ANALYSIS AND CERTIFICATION TEST OF HIGH PERFORMANCE MAGAZINE PIT COVERS

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ABSTRACT

The High Performance Magazine (HPM) is currently under development at the Naval Facilities Engineering Service Center (NFESC). The performance goals of the HPM are to reduce encumbered land and improve operational efficiency. By dividing the HPM into storage pits separated by nonpropagation walls, the maximum credible event can be substantially reduced. A critical component of the HPM is the pit cover. The primary purpose of the pit cover is to prevent sympathetic detonation in the storage pit caused by fragments coming from an accidental explosion during ordnance transport. The pit cover must be constructed such that sympathetic detonation is prevented when the pit cover impacts an acceptor ordnance.

An arena test which examined the fragment penetration resistance of candidate cross sections was conducted. Lightweight concrete specimens constructed with and without steel face plates were subjected to the detonation loads from a MK-84 bomb (945 lb. TNT) at a standoff distance of eight feet. The results show that a twelve inch lightweight concrete section is sufficient to stop the worst case donor fragments.

The finite element program DYNA3D was used to examine the response of the critical thick case acceptor (MK-82 bomb) subjected to pit cover impact. Predicted case deformation and peak pressure in the explosive fill were compared with sympathetic detonation criteria to determine the feasibility of using lightweight concrete as the pit cover material. The results indicate that the pit cover debris will not cause sympathetic detonation when the impulse loading on the pit cover is less than 16 psi-s.

INTRODUCTION

The High Performance Magazine (HPM) is currently under development at the Naval Facilities Engineering Service Center (NFESC). The primary goal of the HPM is to improve the efficiency of land use by reducing the land area encumbered by Explosives Safety Quantity Distance (ESQD) arcs. To achieve this goal, the magazine is divided into storage pits that are separated by nonpropagation walls. The design of the storage pit allows each pit to be treated as a separate magazine. The maximum credible event is then limited to the net explosive weight stored in an individual pit.

Each storage pit is covered by a series of panels called pit covers. The purpose of the pit covers is to protect ordnance in the storage pits if an accendental explosion occurs when munitions are being transported by the overhead crane. It is not feasible to design the pit covers

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to remain intact after an accidental explosion. Therefore, the pit covers are designed to remain in place only long enough to stop fragments. Consequently, the pit covers must be constructed in a way that ensures that sympathetic detonation is prevented when the pit cover impacts acceptor ordnance.

This project was divided into two phases. The focus of the first phase was to determine the fragment penetration resistance of candidate cross sections. This was accomplished by conducting an arena test in which lightweight concrete specimens were subjected to a MK-84 bomb detonated in the close-in range. The second phase was an analytical study to show that the impact of the pit cover would not cause sympathetic detonation in the acceptor pit. Tancreto et al. (1994) used AUTODYN 2D to show that the impact loads were less than the threshold loads required to cause sympathetic detonation of thin-case acceptors. This paper focuses on thick-case acceptors. The explicit finite element program DYNA3D was used to examine the response of the critical thick-case acceptor subjected to pit cover impact.

This paper discusses the pit cover concept and presents the results of the arena test and finite element analysis. The paper concludes with recommendations for pit cover design.

DESCRIPTION

The High Performance Magazine is shown in Figs. 1 and 2. The magazine is divided into two storage areas with the shipping and receiving area located in the center. The nonpropagation transfer aisle walls dividing each storage area into two storage pits can be seen in Fig. 2. Each storage pit can be further subdivided into cells with relocatable nonpropagation cell walls as shown in Fig. 3.

The storage capacity of each cell is limited to 30,000 lb NEW. Only one cell is allowed to be open at a time. The capacity of the shipping and receiving area is limited to 60,000 lb NEW. However, the combined capacity of the open cell plus the shipping and receiving area must not exceed 60,000 lb NEW. Ordnance is transported above the aisle walls by an overhead crane system. The maximum NEW for transported ordnance is 4,200 lb.

ARENA TEST

OBJECTIVE AND SCOPE

The objective of this test was to determine the capability of different cross sections to resist fragment penetration and to identify the minimum thickness required to completely stop the fragments from perforating the pit covers. Eight different cross sections were tested using the worst case fragment donor.

TEST SETUP

The site plan and section view of the test setup are shown in Figs. 4 and 5. The explosive donor was a single MK-84 bomb with an NEW of 945 lb. This is the worst case donor for an accidental explosion in the HPM transport aisle. The MK-84 bomb was placed in the vertical position and the specimens were positioned around the bomb at a distance of eight feet. The bomb was placed with its center of gravity at the same elevation as the centroid of the panels. The specimens were placed at an angle of 30 degrees as shown. This stand-off distance and position were chosen to reflect HPM design conditions.

The specimens were fabricated from lightweight concrete and reinforced with #3 Grade 60 deformed bars on five inch centers top and bottom. The lightweight concrete had a density of 80 lb/ft^3 and a 28 day compressive strength of 2500 psi. The specimens were 4 ft. by 4 ft. with the thicknesses given in Table 1. Panels 3 through 7 had steel sheets on the side of the specimen facing the bomb. The thickness of each steel sheet is also given in Table 1. An additional panel, not shown in the figure, made of 18 inches of CEMCOM CBC was also tested. The CBC material had a density of 65 lb/ft^3 and a compressive strength of 2500 psi. This panel did not have a steel face sheet attached.

Because the specimens break apart after the explosion, no reliable penetration data can be obtained from examining the panels directly. Instead, steel witness plates (1 inch thick) were used to determine if fragments perforated the concrete specimens. These plates were placed directly behind each specimen with a gap of one inch between the plate and the specimen. Complete perforation can be determined by inspecting the witness plates for marks or indentations.

Table 1. SPECIMEN SCHEDULE

PANEL NUMBER	THK. OF LIGHT WEIGHT CONCRETE	THK. OF STEEL FACE SHEETS*
1	12”	0
2	16”	0
3	12”	1/16”
4	12”	1/8”
5	14”	1/8”
6	16”	1/8”
7	20”	1/8”

* A607 Grade 50 Steel

RESULTS

As expected, the blast pressure resulted in the specimens breaking up into small pieces. The largest piece of debris had dimensions on the order of six inches. Panel No. 1 (12 inch thick, no face sheet) had two small indentations on the witness plate indicating fragments perforated the specimen. No perforations were observed in the other panels.

The perforations in Panel No. 1 were located near the top edge. No perforations were observed at the panel centroid where the environment is most severe. This indicates that the perforations were due to edge effects resulting from lack of confinement in the concrete. Since perforations close to the edge of the specimen are of no consequence in the performance of the full scale pit covers, twelve inches was selected as the minimum thickness required to completely stop the fragments from impacting the acceptors.

IMPACT ANALYSIS

OBJECTIVE AND SCOPE

An accidental explosion in the open cell, shipping and receiving area, aisle transport, or in any combination of these will result in an impulse load being applied to the pit covers. This impulse will cause the pit cover to break up and the resulting debris will impact the acceptors that are stored in the closed pits. The objective of the impact analysis was to determine the maximum impulse that can be applied to a twelve inch pit cover without causing sympathetic detonation in the acceptors.

Sympathetic detonation criteria for thin-case munitions (torpedoes, mines, and warheads) are based on the unit impulse and energy impact loads from the pit cover. An AUTODYN analysis showed that the impact loads from the pit cover were well below the design threshold levels for the HPM. (Tancreto et al., 1994) The present paper addresses thick-case munitions (bombs and projectiles). The sympathetic detonation criteria for thick-case munitions is based on the actual response of the acceptor (case deformation and pressure in the explosive fill) and is described below.

CRITERIA

The sympathetic detonation criteria for thick-cased munitions are described by Tancreto et al. (1994). Sensitivity thresholds for peak explosive fill pressure and case deformation are given for selected munitions. The MK-82 bomb and the M107-155mm projectile are considered to be the most sensitive acceptors among the thick-case munitions to be stored in the HPM. Since the M107-155mm is stored in the vertical position, the impact forces from the pit cover debris will act along the axis of the projectile and will result in less case deformation and a lower likelihood of causing detonation. For this reason, the MK-82 bomb was selected as the critical acceptor for the impact analysis. Tancreto et al. (1994) suggest 4.0 kbar as the detonation threshold for peak pressure in the explosive fill and 25 percent as the threshold for relative case deformation. (Relative deformation is defined as the case displacement divided by the original diameter.)

FINITE ELEMENT MODEL

The explicit Lagrangian finite element code DYNA3D (Whirley and Englemann, 1993) was used to conduct an analysis of the pit cover debris impacting a MK-82 acceptor. Shell elements were used to model the steel bomb casing and three dimensional solid elements were used to model the explosive fill. The isotropic elastic-plastic material model was used for the explosive fill and the material properties were obtained from Hall and Holden (1988). The pit cover debris was modeled with three dimensional solid elements using the isotropic elastic-plastic-hydrodynamic material model. The reinforcing steel was not included in the analysis.

Two models were used in the analysis. The first model is shown in Fig. 6. The model consists of a single MK-82 bomb resting on a rigid floor. The second model, shown in Fig. 7, consists of two bombs. This model was used to determine if stacking the munitions produced additional pressure concentrations at the interface of the two bombs. As shown in the figures, it is assumed that the maximum size of pit cover debris will be approximately equal to the projected area of the acceptor. The results of the arena test indicate that this is a conservative assumption. The pit cover density is 75 lb/ft^3. The pit cover debris was given an initial velocity determined by

$v = i/m$ where i = specific impulse (psi-ms) and m = specific mass (psi-ms^2/in). Inherent in this approach is the assumption that there is no energy dissipated as the pit cover breaks up.

RESULTS

Figure 8 shows a sequence of mesh plots from the single bomb model for an initial pit cover velocity of 1000 ft/sec (i = 16 psi-s) . A sequence of cross section plots showing the case deformation and debris breakup is shown in Fig. 9. Figure 10 is a longitudinal cross section through the bomb showing the progression of the pressure wave through the explosive fill.

The relative displacement versus time is shown in Fig. 11. For the given impulse, the relative deformation is approximately 23 percent. The maximum deformation occurs at about 1.2 ms after impact.

The pressures associated with the explosive fill are plotted in Fig. 12. This figure plots the pressure versus time for a point on the top (impact side) and bottom of the explosive fill. The peak pressure for this case is about 2.2 kbar and occurs on the top of the acceptor at about 70 μs.

The relationship between the impulse load on the pit cover and the peak pressure for both models is shown in Fig. 13. The results are essentially the same for both cases. The peak pressure always occurred in an area of the explosive fill close to where the debris first impacts the acceptor. In the two bomb model, there were high pressures calculated near the interface between the two bombs but these pressures were well below those occurring on the impact side of the top bomb. For the range of impulses considered, the predicted pressure is below the 4 kbar threshold value for sympathetic detonation reported in Tancreto et al. (1994).

Figure 14 shows the relationship between the impulse loading on the pit cover and the relative case deformation for the two models. As the figure shows, the deformation was greatest in the single bomb model. (Although bombs are typically stacked on pallets while stored, it is recommended that the single bomb model be used since this represents the worst case scenario.) The peak threshold value for relative case deformation reported in Tancreto et al. (1994) was 25 percent. This value was reached at an impulse of just above 16 psi-s.

CONCLUSIONS

An arena test was conducted to examine the penetration resistance of candidate cross sections for the HPM pit covers. The results show that a twelve inch lightweight concrete section is sufficient to stop the worst case donor fragments.

The response of a MK-82 bomb subjected to pit cover debris impact was evaluated. The results indicate that the case deformation is the dominant criterion. The results further show that the case deformation will be less than the threshold value if the impulse load is below 16 psi-s.

Preliminary calculations suggest that the actual impulse loading on the pit covers will be approximately 10 psi-s. This is substantially less than the 16 psi-s threshold. Therefore, it is recommended that the pit covers be constructed of twelve inch thick lightweight concrete panels.

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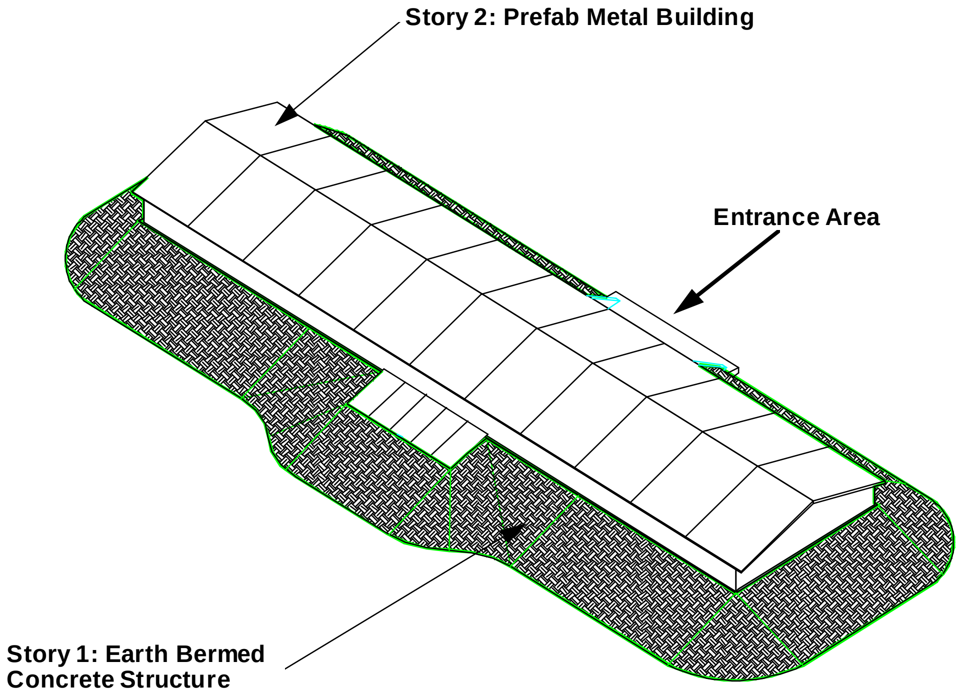


Figure 1. High Performance Magazine; Isometric View

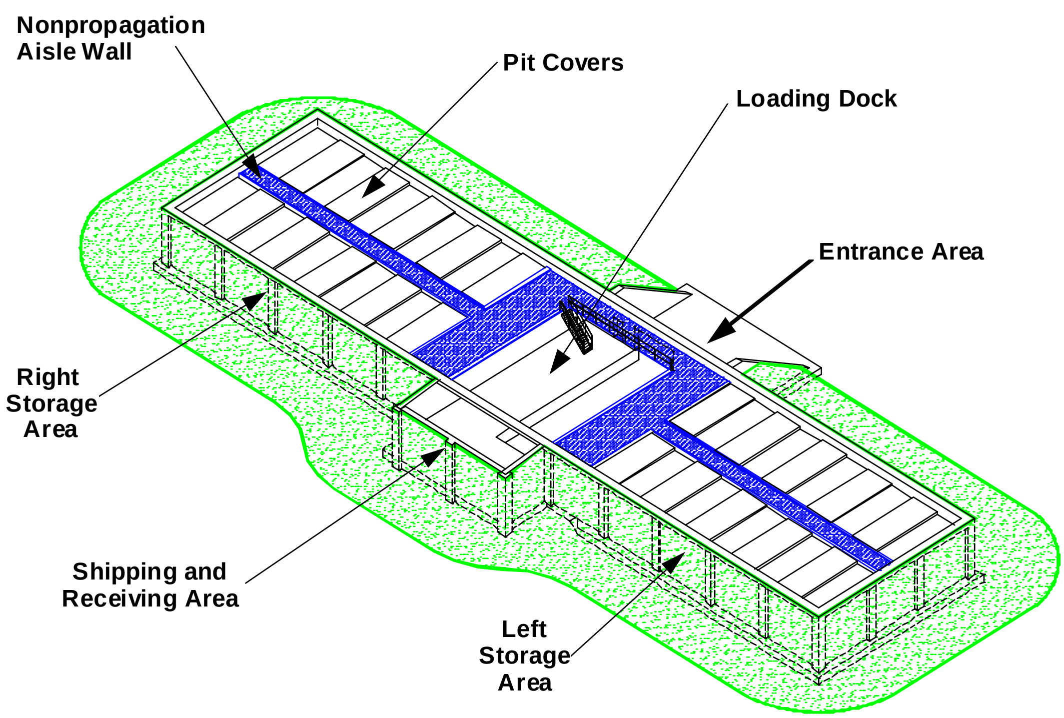


Figure 2. High Performance Magazine; Major Areas

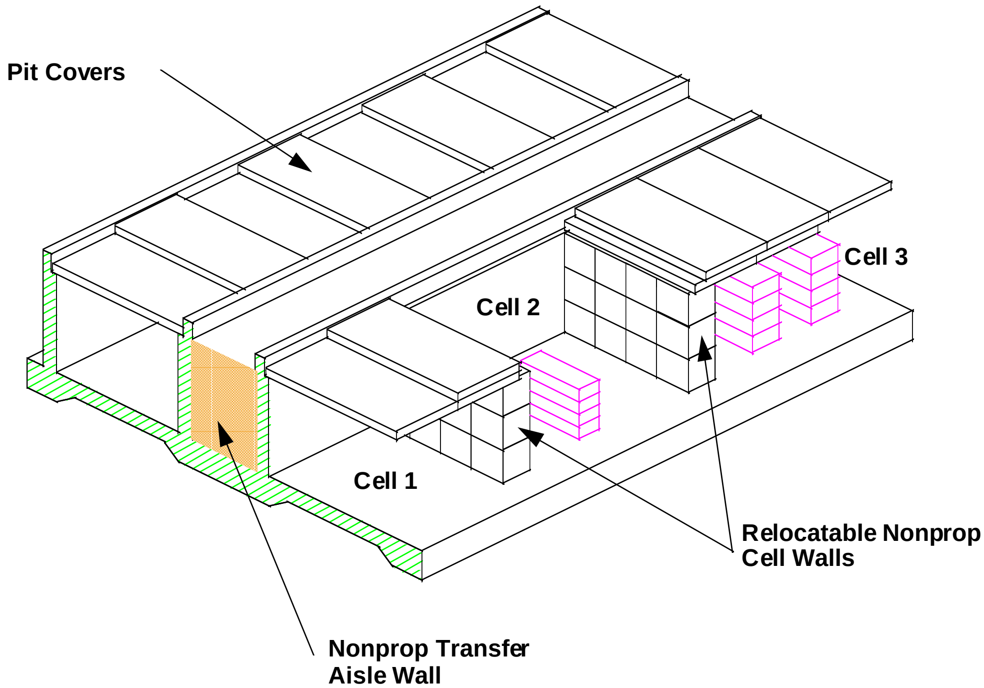


Figure 3. Storage Cells

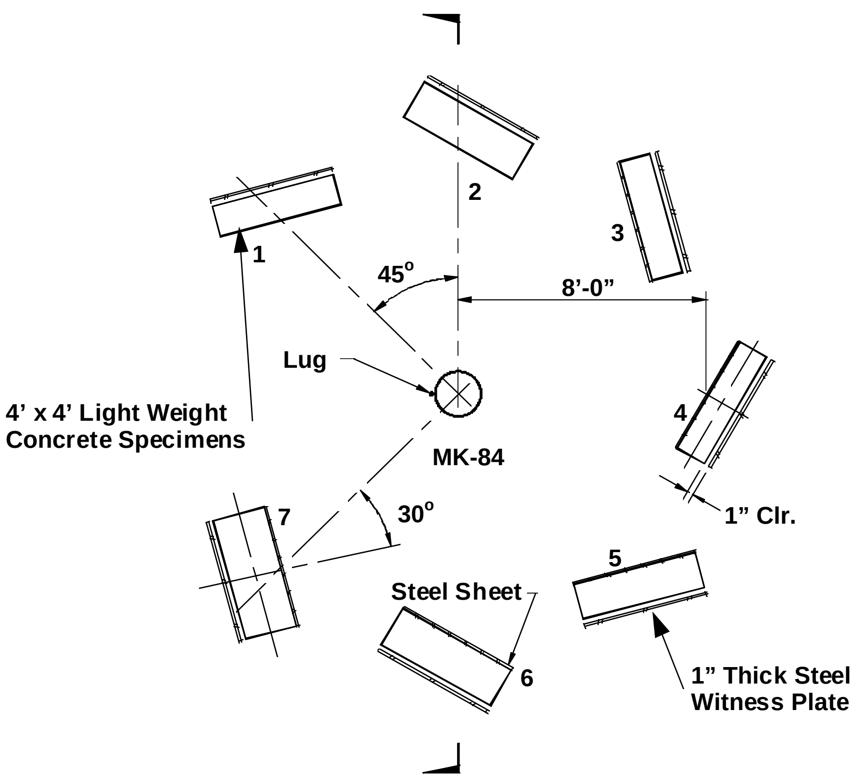


Figure 4. Arena Test Site Plan

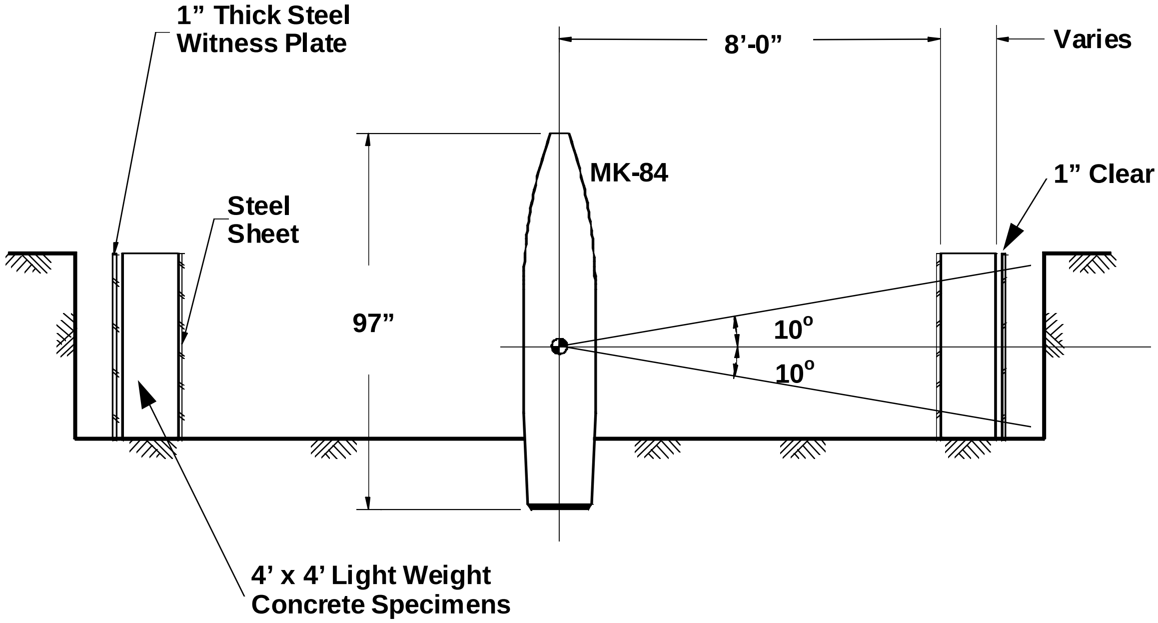


Figure 5. Arena Test Section View

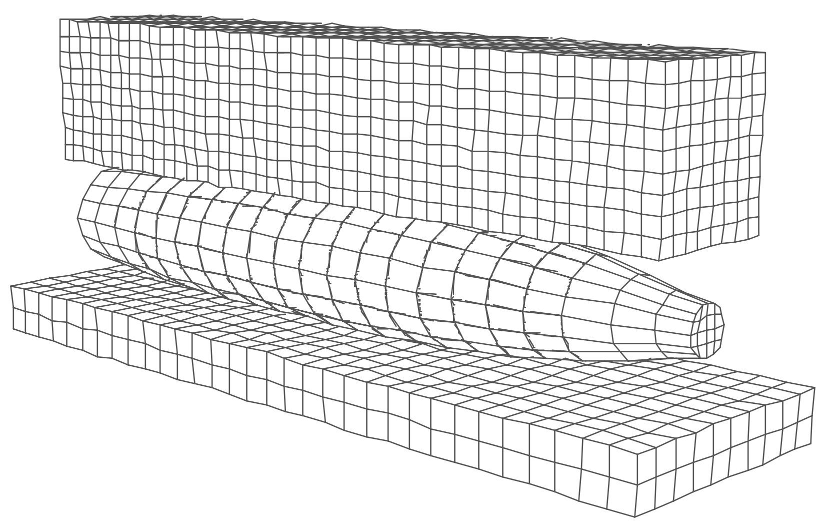


Figure 6. Finite Element Mesh; Single Bomb Model

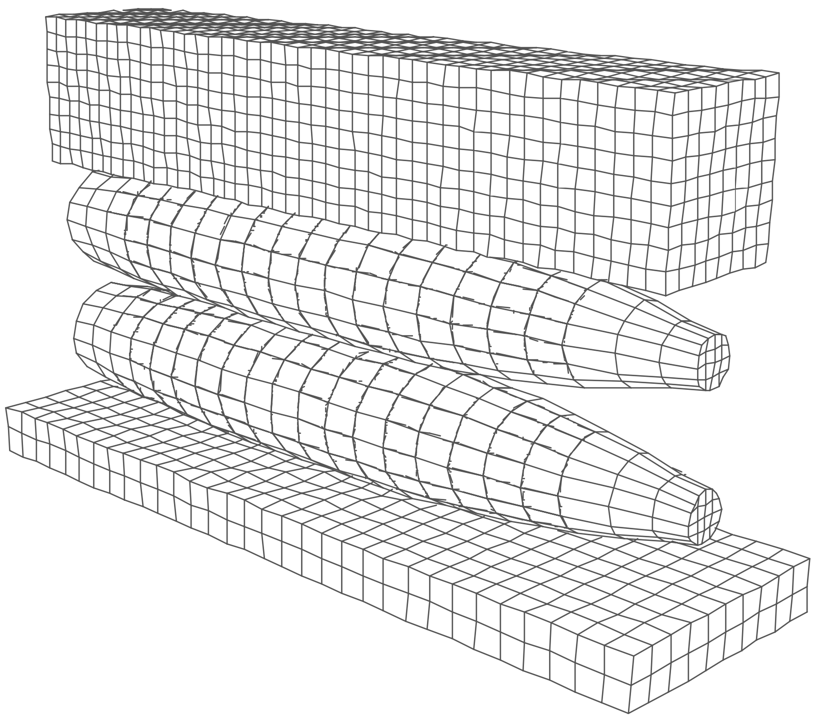
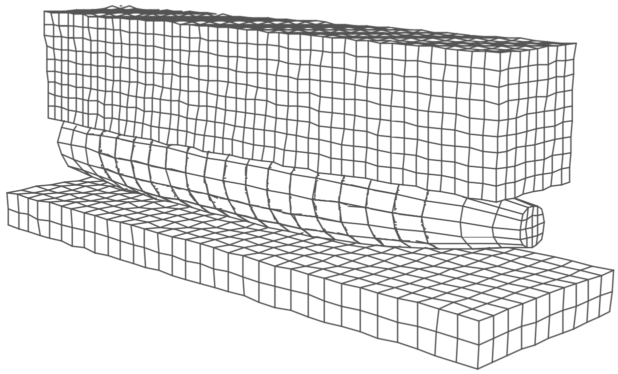


Figure 7. Finite Element Mesh; Two Bomb Model



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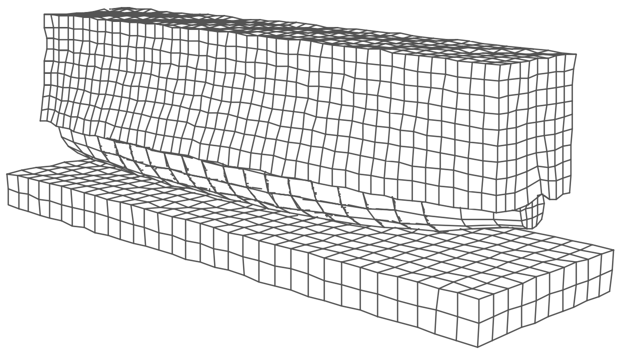

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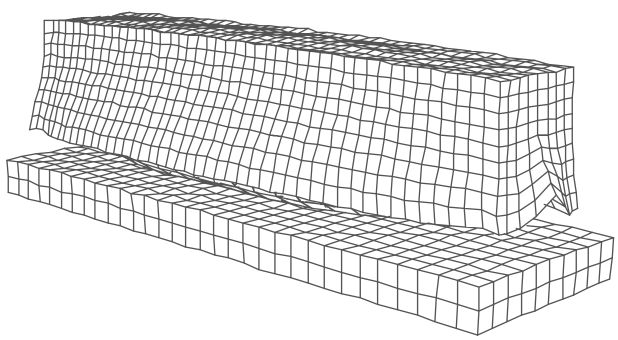
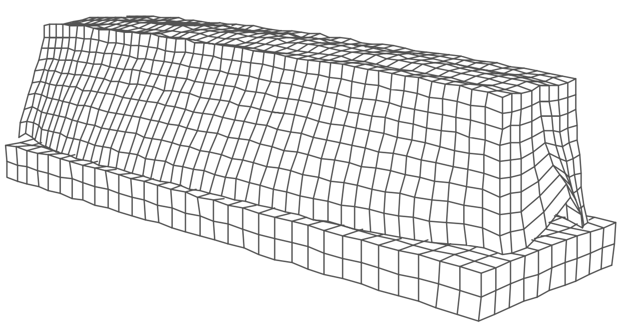
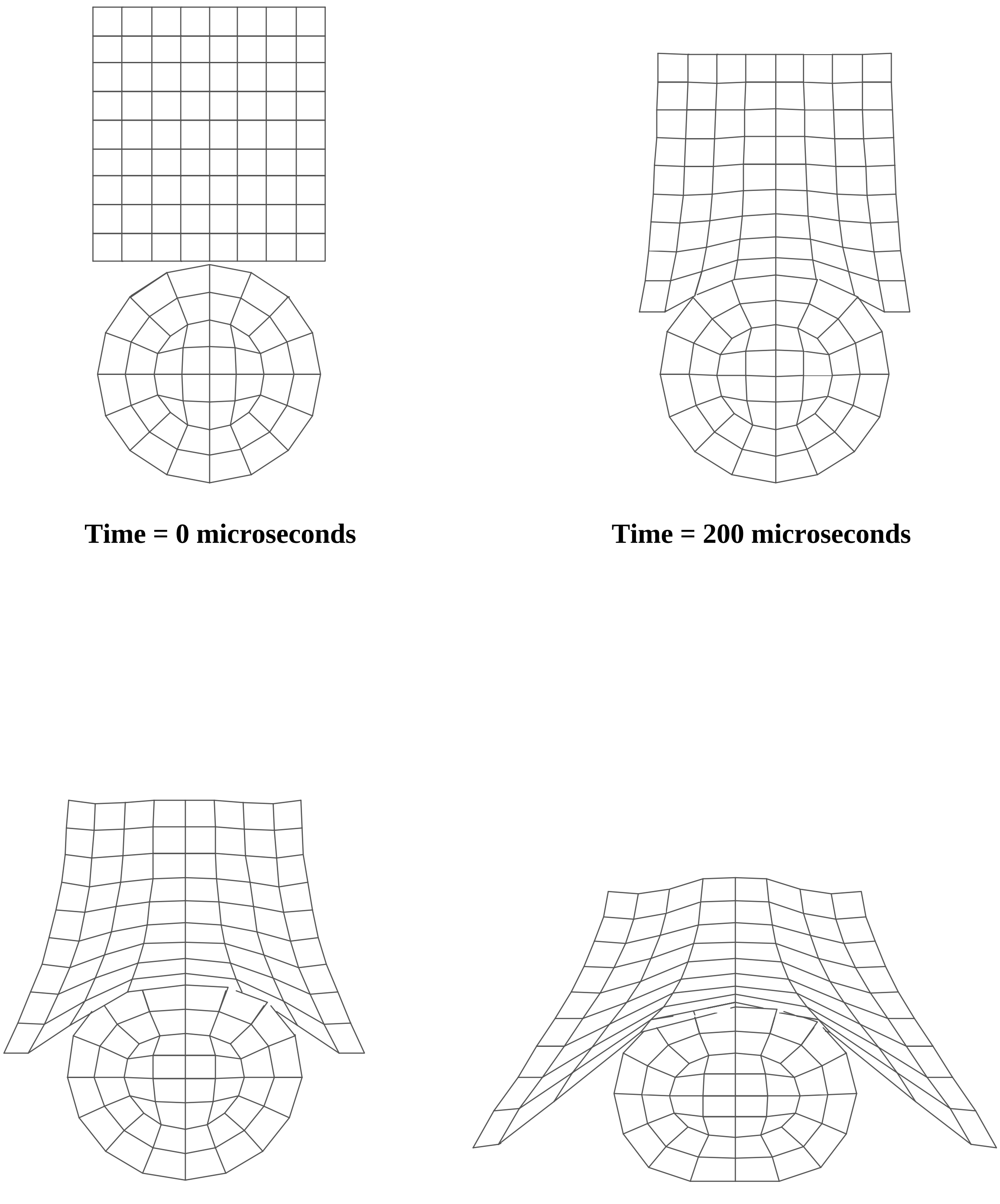


Time = 600 microseconds



Time = 800 microseconds

Figure 8. Sequence of Mesh Plots



Time = 0 microseconds

Time = 200 microseconds

Time = 400 microseconds

Time = 800 microseconds

Figure 9. Sequence of Cross-Section Mesh Plots

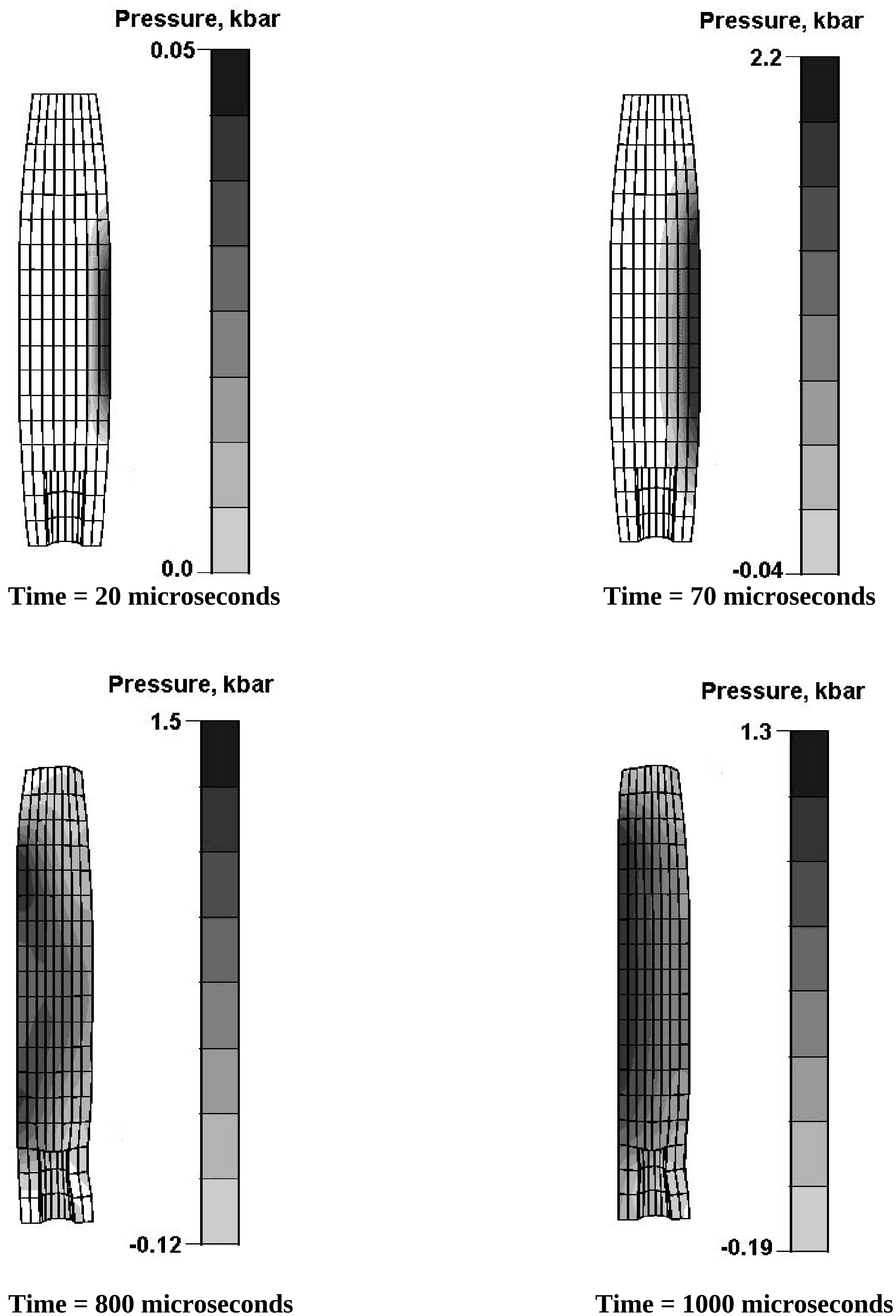


Figure 10. Sequence of Pressure Contour Plots

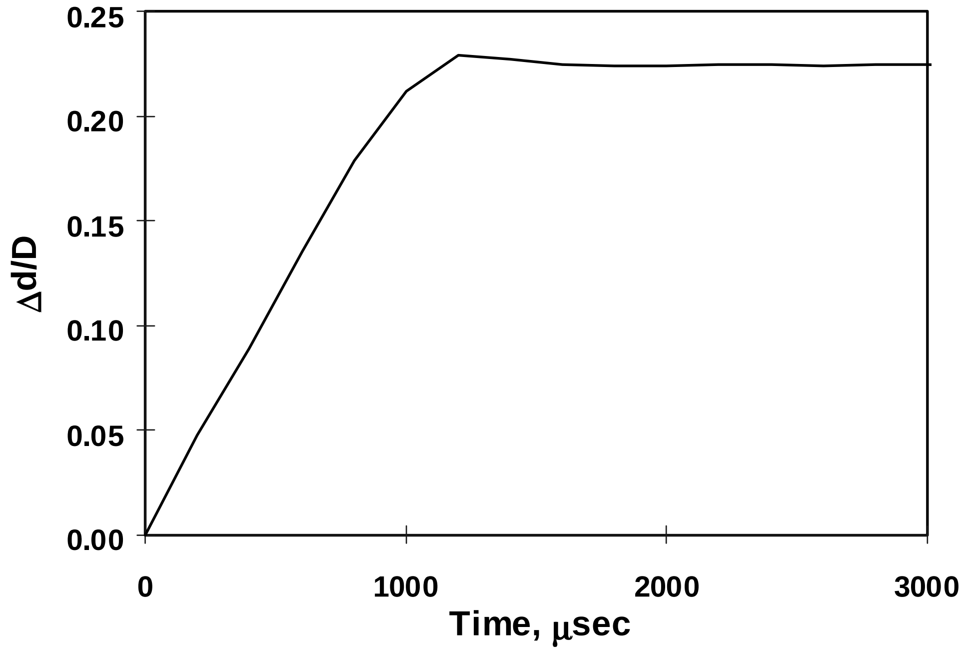


Figure 11. Relative Displacement; Impulse = 16 psi-s

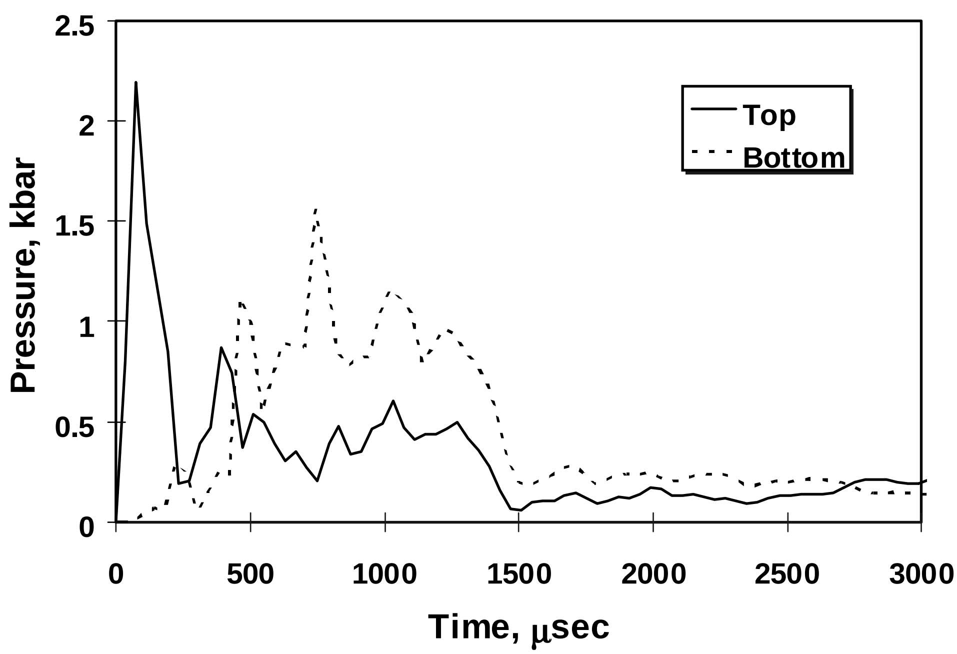


Figure 12. Fill Pressure; Impulse=16 psi-s

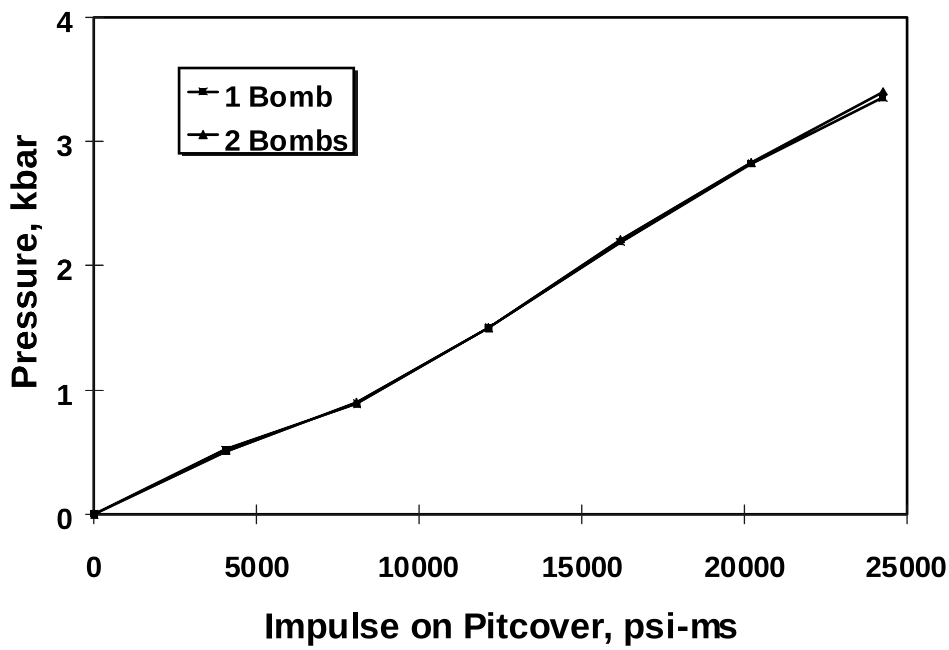


Figure 13. Peak Pressure in Explosive Fill vs. Impulse on Pit Cover

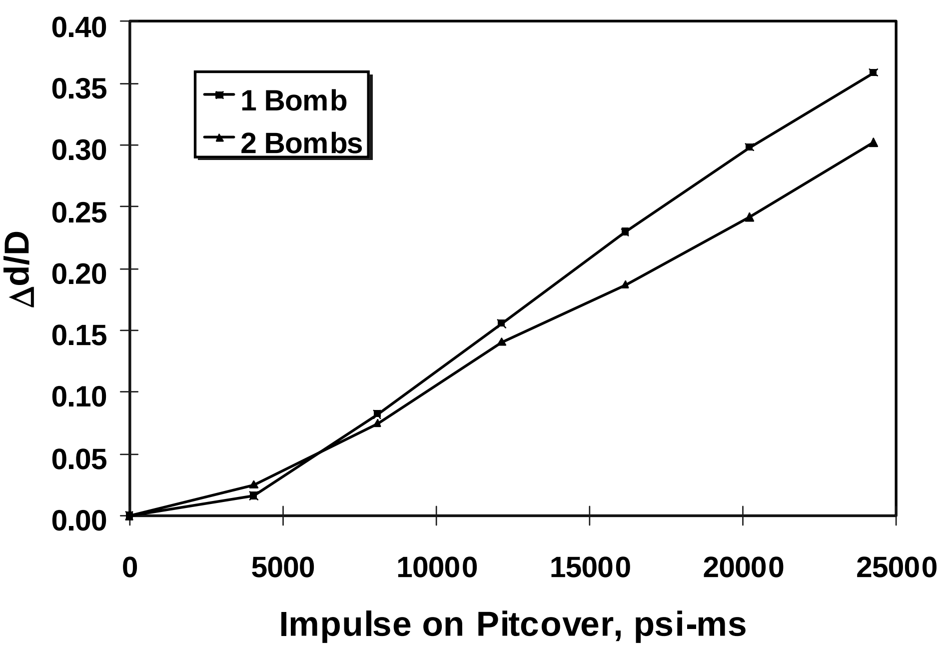


Figure 14. Peak Relative Deformation in Bomb Casing vs. Impulse on Pit Cover